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Peatlands of the Western Siberian lowlands: current knowledge on zonation, carbon content and Late Quaternary history

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Abstract

The Western Siberian lowlands (WSL) are the world's largest high-latitude wetland, and possess over 900,000 km^2 of peatlands. The peatlands of the WSL are of major importance to high-latitude hydrology, carbon storage and environmental history. Analysis of the existing Russian data suggests that the mean depth of peat accumulation in the WSL is 256 cm and the total amount of carbon stored there may exceed 53,836 million metric tons. A synthesis of published and unpublished radiocarbon dates indicates that the peatlands first developed at the end of the Last Glacial, with a rapid phase of initiation between 11,000 and 10,000 cal yr BP. Initiation slowed after 8000 cal yr BP and reached a nadir at 4000 cal yr BP. There has been renewed initiation, particularly south of 62°N, following 4000 cal yr BP. The initial development of peatlands in the WSL corresponds with the warming at the close of the Pleistocene. Cooling after 4000 Cal yr BP has likely led to increased permafrost and increased peatland development particularly in central and southern regions. Cold and dry conditions in the far north may have inhibited peatland formation in the late Holocene.

1. Introduction

The Western Siberian lowlands (WSL) are the world's largest high-latitude wetland, with a forest-palustrine zone of about 1,800,000 km^2 that covers nearly 2/3 of West Siberia (Zhulidov et al., 1997). In size the WSL ranks second only to the Amazon Basin among the world's largest wetlands (Aselman and Crutzen, 1989). At least half of this area consists of peatlands (Fig. 1) (Neustadt, 1971; Zhulidov et al., 1997). These northern peatlands are a major pool of stored carbon and significant component in planetary carbon sequestration and emission calculations (Franzen, 1994; Botch et al., 1995). The impact of the peatlands on the discharge, geochemistry, and sedimentology of the Ob' and Yenisei Rivers is of undoubted major importance to the hydrology of the Arctic Ocean and potentially to global ocean circulation and climate. Palaeoenvironmental data on the history of the peatlands and how past climatic changes have impacted them could provide important information for anticipating the effects of future "global warming". The development of the peatlands over the Late Quaternary had a major impact on the human land-use of the Arctic coastal region, which dates from at least the Mesolithic (Praslov, 1984). Understanding the history of the peatlands is important in interpreting Late Quaternary palaeontological and archaeological records.

Despite their importance, there remains relatively little known about the WSL, particularly outside the Russian language literature. Basic information about peatland age, thickness, and seasonal inundation range is sparse (e.g. Botch and Masing, 1983; Neustadt, 1984; Franzen, 1994; Botch et al., 1995). Whether the area was glaciated during the Last Glacial Maximum (LGM) is a topic of continued debate (Frenzel et al., 1992; Velichko et al., 2000; Mangerud et al., 2002; Grosswald and Hughes, 2002). Information on Holocene climate change and its impact on the peatlands comes from scattered sources. Total carbon content, rates of carbon sequestration and greenhouse gas exchange, remain

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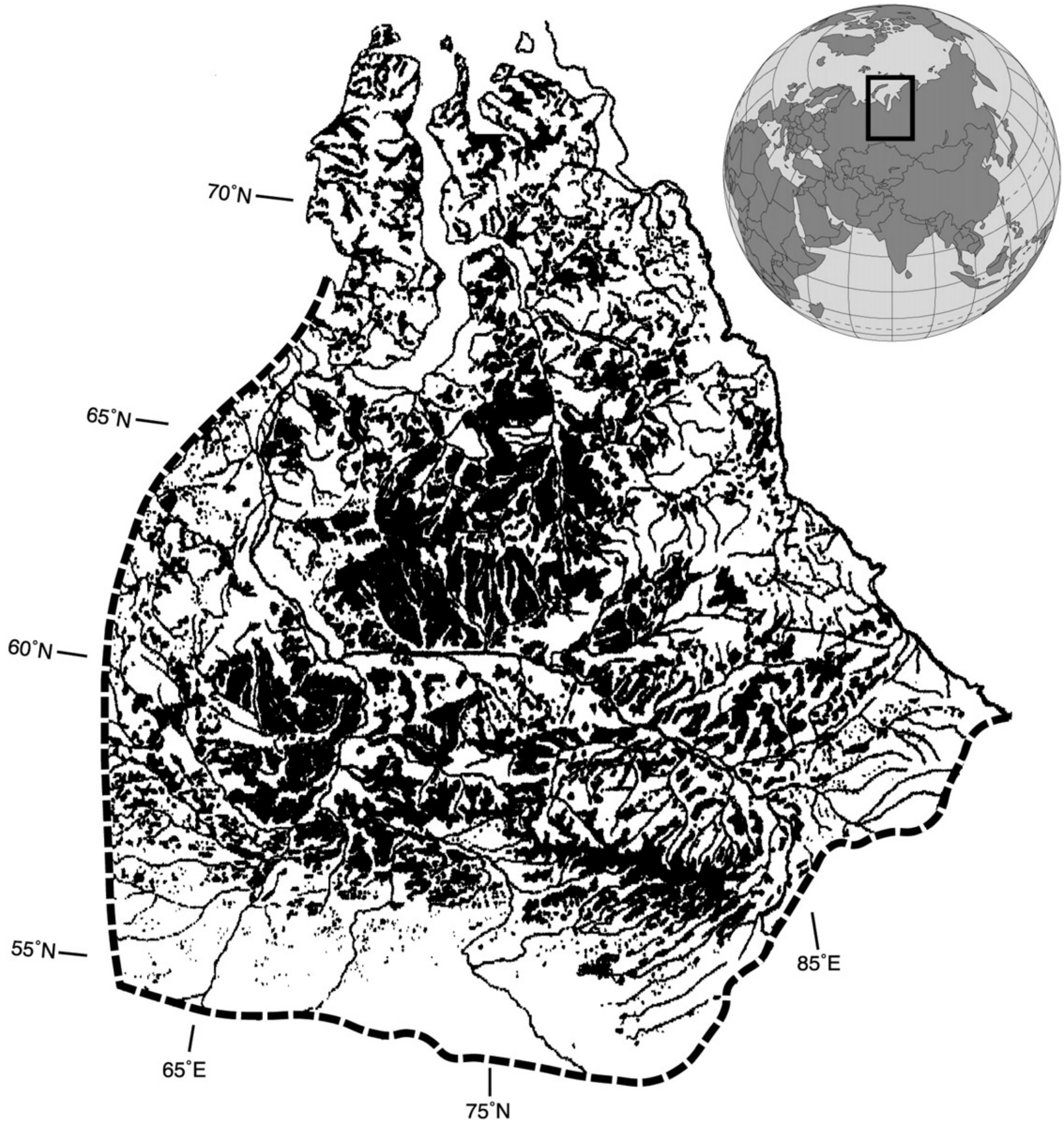

Fig. 1. The Western Siberian Lowlands and general extent of peatland cover (black areas) (after Ivanov and Novikov, 1976).

poorly known and have only been coarsely estimated (Botch and Masing, 1983, Franzen, 1994; Botch et al., 1995). In discussing carbon reservoirs in the Former Soviet Union, Botch et al. (1995, p. 42) state "the main sources of uncertainty in the estimates presented herein are associated with the areal extent of FSU peatlands and depth of peat deposits''.

In this paper we review the Russian literature pertaining to the modern environment and phytohydrologic zonation of the WSL, current estimates of carbon volume in terms of peat storage, and Late Quaternary history of the peatlands. The goal of this review is to provide as comprehensive a synthesis as possible of Russian literature regarding the current state of the Western Siberian peatlands, their Late Quaternary development and sensitivity to Holocene climatic changes. Such a synthesis is essential for understanding the relationship between the peatlands and climate change, and for planning further investigations of this critical region.

2. Regional setting

2.1. Geology

Extensive peatland cover and flat relief make it difficult to study the geology of the WSL region. The igneous basement of the West Siberian platform is formed by Palaeozoic rocks that are mainly Herzine and Caledonian in age. These rocks are overlain by Mesozoic and Cenozoic sedimentary deposits. The

Meso–Cenozoic sediments can range up to 3000–6000 m in thickness. Quaternary deposits with depths of up to 200–250 m cover the West Siberian lowland (Volkov and Oliunin, 1993). The geographic extent of the glacial cover over West Siberia during the Quaternary remains poorly documented. Where exposed, the Quaternary sediments often consist of sands and other aeolian and fluvial deposits. It appears unlikely that any of the region was glaciated in the LGM. Earlier in the Quaternary ice may have been present along the Arctic coast (Arkhipov, 1984; Velichko et al., 1984; Frenzel et al., 1992). However, the exact extent of Late Quaternary glaciation remains debated (e.g. Velichko et al., 1984, 2000; Grosswald, 1998; Grosswald and Hughes, 2002; Faustova and Velichko, 1992).

2.2. Physiography

The topography of the WSL is generally flat. Total topographic relief ranges from sea level along the Arctic coast to maximum elevations of approximately 200 m in the interior. A gently rising, broad upland, the Sibirskie Uvaly Hills, runs from west to east across the WSL at about 63°N latitude. A small amount of local relief is provided by raised peatland hills of several metres height that are found in permafrost regions. Local relief is most pronounced in the river valleys. The valleys of the Ob' and Irtysh rivers achieve widths as large as 20–120 km.The modern floodplains on these large, low gradient rivers are only 3–8 m above the mean river level. A well documented set of Quaternary river terraces is observed at higher levels and reach heights of over 60 m above the modern floodplain. In the valleys of big rivers, such as the Ob' and Irtysh, at ~100 m depth there are at least four early and mid-Quaternary alluvial complexes overlain by younger alluvial sediments (Baulin et al., 1967; Arkhipov et al., 1999).

Although histosols dominate the WSL, sands and loams are common where mineral soil is exposed. The Sibirskie Uvaly Hills contain relatively large areas of exposed sand and loams. Sands and loams are also the most common material underlying peatlands. Those areas that are not dominated by peatland histosols are typified by forested spodosols in south and central regions, and tundra regosols, gleysols, and cryosols in the far north.

Continuous permafrost extends southward from the Arctic coast to approximately 64°N latitude (Fig. 2). Cryogenic features such as peat polygons are common in the far north. Discontinuous permafrost is found to about 60°N latitude, with sporadic permafrost occurring south of that. The impact of widespread permafrost in restricting soil drainage contributes to the extensive development of peatlands in the WSL. North of the Arctic Circle the thickness of the permafrost varies from 300 to 600 m. The depth of the active layer ranges here from 20 to 200 cm. Southward to about 64°N the thickness of the permafrost ranges from 200 to 400 m with the active layer being 30 – 400 cm deep. Near the southern limit of continuous permafrost its thickness varies from 50 to 300 m (Baulin et al., 1967, 1984). The temperature of the permafrost is as low as −9°C in the north and increases in a relatively consistent manner southward (Fig. 2). The development of permafrost was initiated in the Early Pleistocene and reached its maximum extent during the Last Glacial epoch (Velichko and Nechaev, 1984). During the early and mid-Holocene the limit of continuous permafrost may have retreated to 68°N in the west and at 70°N in the east. Climatic deterioration in the late Holocene appears to have triggered a new phase of permafrost expansion (Velichko and Nechaev, 1984). Thus, south of 66°N an upper permafrost layer is separated from a lower layer of permafrost by a zone of thawed sediments that are relicts of deep melting during the mid Holocene (Fig. 2).

2.3. Climate

Climate in West Siberia is cold and continental. Mean January temperature in the northern half of the WSL is −14°C to −28°C, and −14 to −20°C in the southern half (Fig. 3a). The summer is warm with mean July temperature being 17°C to 18°C in the forest belt and declining to 10°C to 12°C near the Arctic coastline (Fig 3b). The duration of the frost-free period is two months in the far north and up to four months in the south.

The annual precipitation is up to 590 mm in the northern portion of the WSL, up to 510 mm in the central portion, and up to 400 mm in the south (Fig. 4). The mean depth of snow cover reaches its maximum in the central portions (up to 80 cm) and then decreases to the south and north. For the most part, precipitation is greater than potential evaporation over the lowlands (Fig. 4). At the southern fringe of the lowlands precipitation and evaporation are in equilibrium and further south in the forest-steppe and steppe belts of Siberia there is less precipitation than evaporation. The generally short summers and positive moisture balance help to promote peatland development in the WSL.

2.4. Hydrology

Rivers and streams are numerous in the WSL. The largest rivers include the Ob' and Irtysh in the west and the Yenisey in the east. The total annual discharge and mean discharge of the Ob' are ~400 km^3 and 12,400 m^3/s, respectively. For the Yenisey the total annual discharge is ~625 km^3 and the mean discharge is 19,800 m^3/s, (Davydova and Rachkovskaya, 1990). Flat relief contributes to the poor drainage and localized

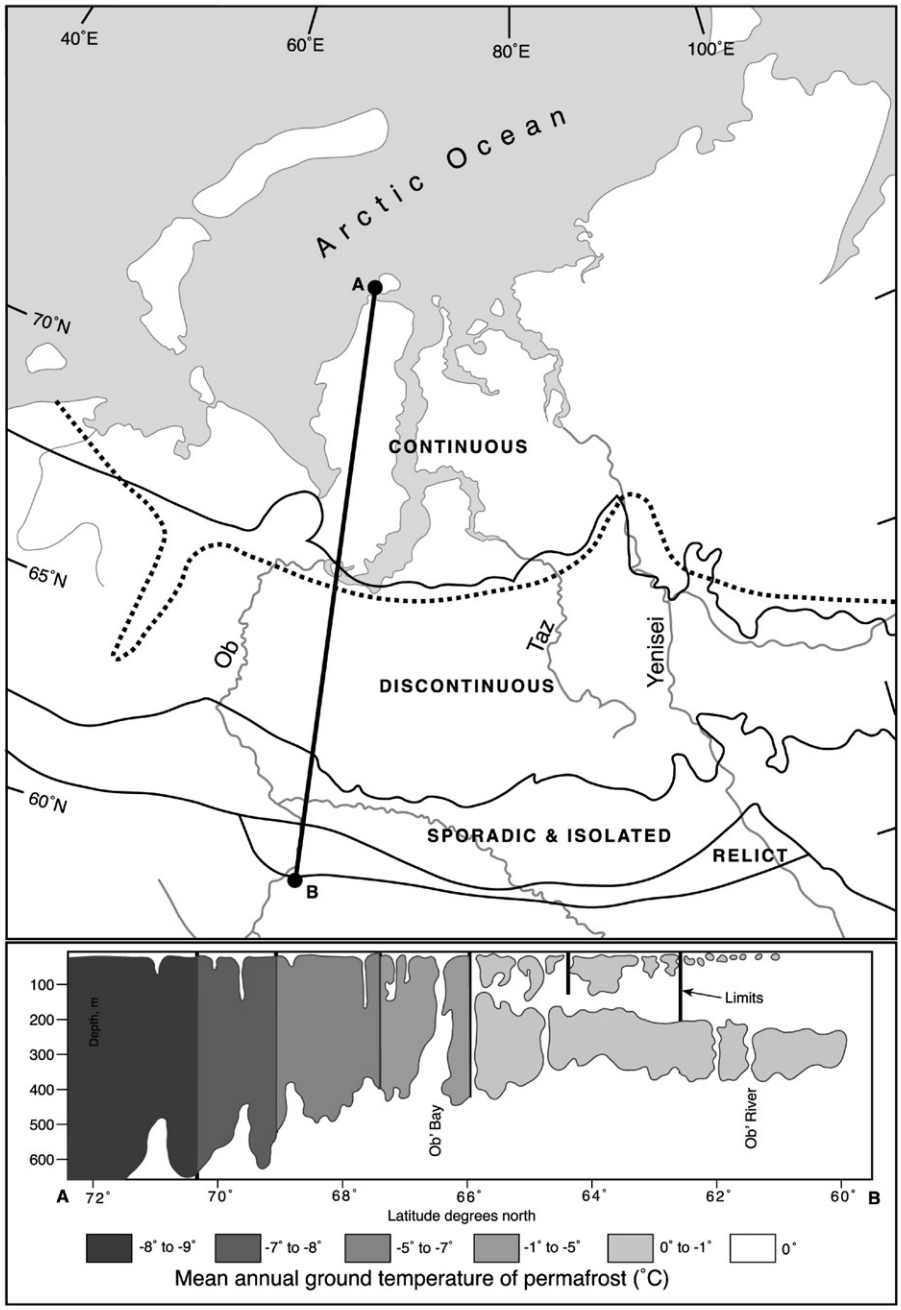

Fig. 2. The current extent and thickness of permafrost in the West Siberian Lowlands (after Brown, 1997; CAPS, 1998).

flooding of the lowland, which are additional factors favourable for peatland development (Walter, 1984). The average gradient of the Ob' River is only 30 m/km (Baulin et al., 1967). In general the regional drainage gradient of the WSL ranges from 10 to 80 m per km (Gorham, 1991). River waters have a low mineral content (0.1–0.2 g/l). The majority of the mineral content in the river waters consists of hydrocarbonates. Lakes are also numerous in the lowland. In some areas lakes make up more than 50% of the total surface area.

2.5. Vegetation

The vegetation of the WSL can be divided into four major latitudinal zones (Fig. 5). The northern part of the lowlands is covered by a tundra belt that grades from sparsely vegetated polygonal tundra dominated by lichens (*Cladonia, Alectoria, Cetraria*) and mosses, with occasional birch and willow (*Betula nana* and *Salix)* shrubby areas and sedge (*Carex)* meadows, to a middle zone with denser vegetation cover and extensive cotton grass (*Eriophorum vaginatum)* meadows, to a southern

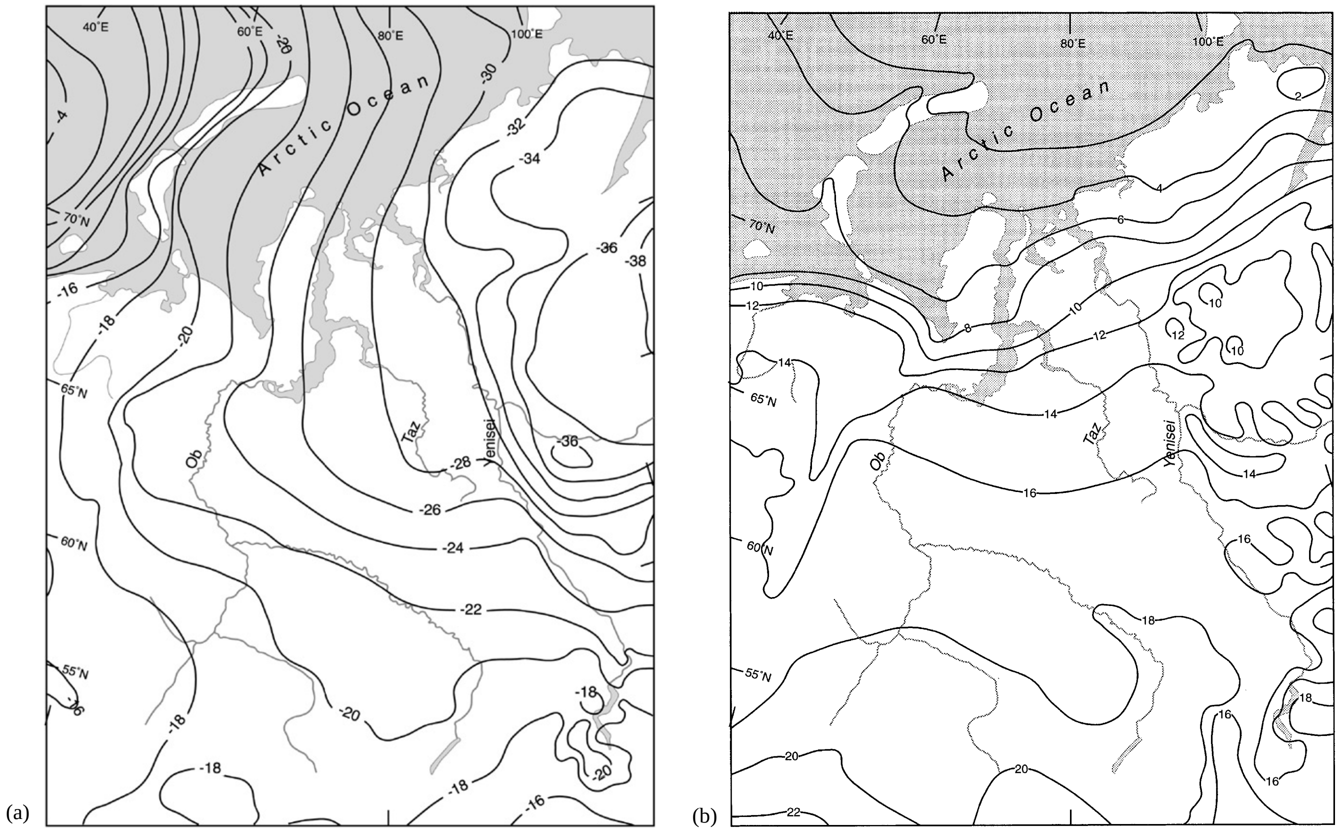

Fig. 3. a. Mean January and b. July temperatures in degrees Celsius(after Davydova and Rachkovskaya, 1990).

zone with dense stands of birch and alder (*Betula nana*, *Betula humilis*, and *Alnus fruticosa)*. Siberian larch (*Larix sibirica)* occurs in river valleys that bisect the southern tundra sub-zone.

South of the tundra there occurs a forest-tundra zone typified by stands of Siberian larch interspersed with tundra vegetation. Birch trees (*Betula pendula* and *B. pubescens)* are also found in this zone. The boreal forest (taiga) zone is typified by Siberian larch, Siberian spruce (*Picea obovata*), Scots and Siberian pine *(Pinus sylvestris, P. sibirica),* Siberian fir *(Abies sibirica)* and birch (*Betula alba)*. Most of the uplands are occupied by forested peatlands, which support small scattered trees. These forested peatlands are usually occupied by larch, pine and some birch. Open Scots pine forests dominate uplands that possess sandy soils such as the Sibirskie Uvaly Hills. Floodplains, such as those of the Ob' and Irtysh, are mainly covered by sedge and grass meadows. Peatlands with birch forest and shrub birch cover can also occur on floodplains. Stands of large trees with continuous canopies generally occur only on the slopes and better-drained portions of river valleys. The southern edge of the WSL is occupied by an ecotone between taiga and steppe. The ecotone is dominated by birch-poplar forest with openings of steppe vegetation.

3. Peatland zonation

Russian scientific literature classifies peatlands into three main types. The classification is based upon the inferred relative stages of peatland development and associated nutrient status. The first stage of peatland development, regardless of peatland origin or initial relief, is the eutrophic stage. The water input to eutrophic peatlands includes groundwater and/or surface water. Thus, these peatlands have relatively high nutrient availability for plants. As the peat becomes thicker, precipitation becomes more dominant in terms of moisture input, and nutrient availability declines. Peatlands in this stage of development are classified as mesotrophic. The last stage of peatland evolution is the oligotrophic bog that depends entirely on precipitation for moisture input. Oligotrophic peatlands have very low nutrient availability and restricted floral composition and vascular plant cover. It is assumed in early Russian peatland literature that all oligotrophic bogs have gone through the eutrophic and mesotrophic stages. It is now accepted that the scheme represents a hypothetical trajectory. Eutrophic and mesotrophic peatlands will not necessarily evolve into oligotrophic bogs. The tripartite scheme described above is an important component in Russian efforts to classify,

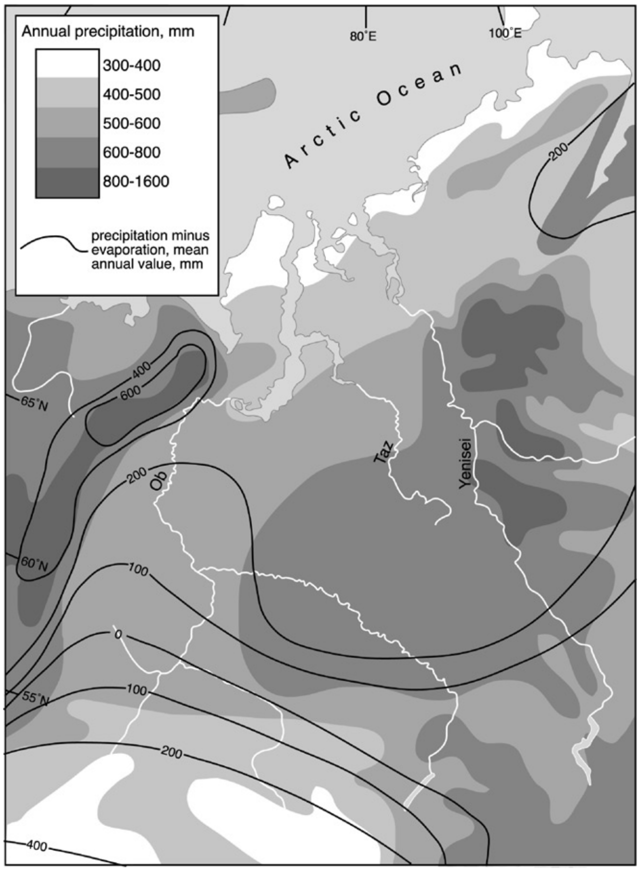

Fig. 4. Average annual precipitation and precipitation minus evaporation (after Davydova and Rachkovskaya, 1990).

Fig. 5. Major vegetation zones of the West Siberian Lowlands (after Davydova and Rachkovskaya, 1990).

map and interpret the history of the peatlands of the WSL.

The first scientific descriptions of the peatlands of the southern portions of the WSL were made in the early 20th century as a part of government sponsored botanical and pedological investigations (Gordiagin, 1901; Zhilinsky, 1907; Dranitsyn, 1914). The first detailed studies that focused on the southern peatlands commenced in the 1920s (Baryshnikov 1929; Bronzov, 1930). Botanical research on the Yamal and Gydan peninsulas in the 1930s provided the first scientific data on peatlands in the arctic part of the WSL (Gorodkov, 1932; Govorukhin, 1933). Following the discovery of oil in the 1950s intensive study of peatlands in the central WSL commenced. Most of these studies were concerned with producing information on peatland distribution and thickness that would be useful for developing roads and infrastructure needed for oil exploration and development. In the 1960s and 1970s investigations continued on the spatial distribution of peatlands, peat thickness, hydrology and vegetation cover (Neustadt, 1971, 1982; Ivanov and Novikov, 1976; Liss and Berezina, 1981). More recently, studies have been conducted on the plant ecology of peatland forests (Glebov, 1988).

During the second half of the 20th century a number of peatland maps were developed for the WSL. For example, Geoltorfrazvedka (a specialized branch of the Russian geological survey that focuses on peat studies) developed a map of peatland distribution in the forest and forest-steppe zones (Karta bolot Zapadnoi Sibiri, 1970, 1996). This map was produced largely from air photographs and so mainly portrayed the geographic distribution of treeless or sparsely forested peatlands. The most useful map for the general zonation of peatlands in the WSL remains the work of Romanova (Ivanov and Novikov, 1976). She established a latitudinal zonation of Eurasian peatlands based on visual differences in the structure and relief of bogs (Fig. 6). We describe the Romanova peatland zones below and also provide some very general information on the thickness of peats within each latitudinal zone.

3.1. Polygonal bog zone

Polygonal peatlands are mainly restricted to tundra areas on the Yamal, Tazovski and Gydan peninsulas. Peatlands in this zone occupy approximately 20–50% of the local landscape. Frost wedges that are 20–100 cm long and 5–80 cm deep form the polygonal structure of

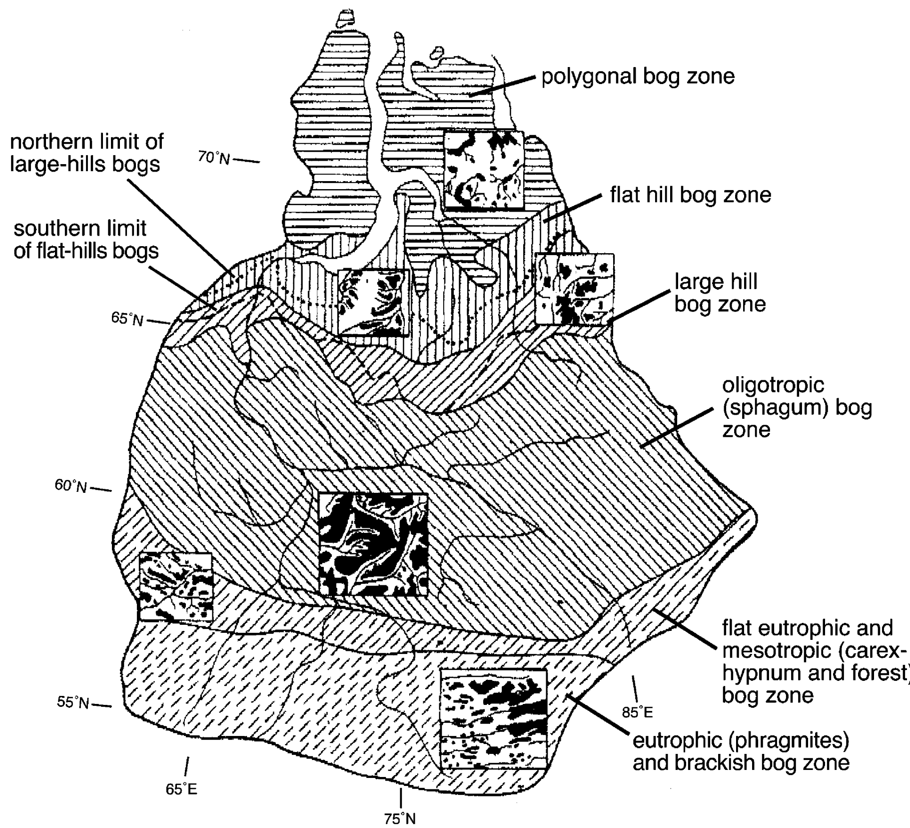

Fig. 6. Major peatland zones of the West Siberian Lowlands (after Ivanov and Novikov, 1976).

the surface of the peatlands. These faults define polygons with sides up to 25 m long. Peatlands in this zone are dominated by *Sphagnum-Hypnum* and *Gramineae-Hypnum* bogs, but include some eutrophic bogs dominated by *Carex*. The peatland cover is discontinuous. Peatlands are often formed in depressions and are surrounded by tundra vegetation developed on mineral soils. Reported peat thickness in polygonal peatlands generally ranges from 20 to 150 cm (Andreev, 1935; Botch et al., 1971). Peat is thickest in the southern portions of the zone (Botch et al., 1971) and may reach depths of 3 to 4 m on the southern Yamal Peninsula (Piavchenko, 1955; Vasilchuk et al., 1983). Depths of peat on the Tazovski Peninsula vary from 1.0 to 5.3 m (Ivanov and Novikov, 1976).

3.2. Flat mound-bog zone

Flat mound-bogs (small mound-bogs according to Gorodkov, 1935) are found mainly in the forest-tundra belt, but also occur in northern part of taiga belt in the zones of discontinuous and sporadic permafrost. In the southern part of the zone they occur together with large hill bogs. Flat mound-bogs represent about 40% of the land cover in the zone. The structure of these bogs is complex. Flat frozen mounds (“bugry”) with lichen and *Sphagnum* vegetation cover are distributed amongst non-frozen depressions (“mochazhiny”) with *Carex-Hypnum* cover. The difference in elevation between the mounds and depressions is generally less than 4 m. The relative area occupied by mounds and depressions is variable, in general the area occupied by mounds is smaller than that occupied by depressions. The peat depth beneath the mounds may be only 25–30 cm and in depressions the peats are typically 100–150 cm thick (Ivanov and Novikov, 1976). In the Ob’ valley near the town of Salekhard peat depths of 0.9–1.2 m have been measured (Katz and Katz, 1948; Piavchenko, 1955). In the Taz–Yenisei watershed peat depths 1–3 m are reported (Piavchenko and Fedotov, 1967). The mound portions of these peatlands are oligotrophic, while depressions are mesotrophic or eutrophic.

3.3. Large mound-bog zone

Large mound-bogs are found in the northern taiga vegetation belt. The southern limit of this zone corresponds to the southern limit of sporadic permafrost. Permafrost in this zone occurs only in peat bogs. Peatlands cover about 25% of the total landscape. Frozen peat mound, of up to 6 m in height, are surrounded by non-frozen depressions. Work by the State Hydrological Institute in Saint Petersburg (Ivanov and Novikov, 1976; Novikov and Usova, 1983; Malyasova et al., 1991; Novikov et al., 1999) established the important role of permafrost in the formation of northern peatland mound. Studies of peat sections showed that under frozen mound-bogs the level of mineral soil is 1–2 m higher than under adjacent unfrozen depressions. However, the composition of basal peat layers is the same under the mounds and depressions. The rise of the mineral soil under the peat mounds indicates that permafrost heaving is responsible for the topography. In some cases the mounds exhibit evidence of erosion and associated degradation of the underlying permafrost (Piavchenko, 1955; Tyrtikov, 1969). The peatland vegetation cover is similar to the Flat Mound-Bog Zone. Coniferous trees often grow on the larger mounds. The mound portions of these bogs are oligotrophic (mainly *Sphagnum* dominated), while depressions may be mesotrophic or eutrophic. The thickness of peat beneath the frozen mounds is often 100–250 cm. Peat thickness in the depressions often ranges up to 300 cm (Tyrtikov, 1969; Ivanov and Novikov, 1976). In rare cases, peat thickness can be up to 3–5 m beneath large mounds (Piavchenko and Fedotov, 1967).

3.4. Oligotrophic (sphagnum) bog zone

This is the largest peatland zone in the WSL. It corresponds with the portion of the taiga vegetation zone that lies south of the limits of permafrost. Peatlands cover about 40% of the total area and in some regions peatlands comprise 70% of the total landcover. Peatland relief in this zone is complex. Elevated portions can stand several metres above the surrounding landscape and they support pine stands. The elevated areas are generally surrounded by wet depressions. Lakes of different size and shape are very common in the landscape. The different sizes and shapes of the rises, depressions and lakes create a large variety of oligotrophic bogs. *Sphagnum* dominates in elevated portions of the peatlands, while *Carex* and *Hypnum* mosses dominate in the depressions. Oligotrophic conditions dominate in this zone. Eutrophic peat occurs largely on floodplains. Mean peat depth north of the Ob' River near the town of Surgut is reported to be about 1.8 m. South from the Ob' valley the mean peat depth is estimated to be 2.5–3.2 m, with some depths reaching over 5 m (Ivanov and Novikov, 1976).

3.5. Flat eutrophic and mesotrophic (carex-hypnum and forest) bog zone

This zone occurs in the southern part of the taiga forest belt. Peatlands occupy about 20% of the landscape. The most common types of bogs here are *Carex-Hypnum*, *Carex, Sphagnum, Carex-Sphagnum, Phragmites* and forest bogs. Forest cover on peatlands generally consists of pine and birch. Oligotropic bogs are less common. Peat accumulation in this zone is variable, but generally the unforested bogs average 1.5 m and can reach 4.0 m in depth. However, depths of the forested bogs are very poorly known (Ivanov and Novikov, 1976).

3.6. Eutrophic (phragmites) and brackish bog zone

This peatland zone is found in the forest-steppe and steppe belts of West Siberia. Peatlands are common only in the northern part of the zone where they mainly occur in valleys. In the southern part of the zone peatlands only occur as swamps near lakes or in topographic depressions. *Phragmites* bogs occur in the northeast part of the zone (Baraba forest-steppe). Small *Phragmites* and *Carex-Phragmites* swamps occur in depressions and in river valleys up to the northern part of Kazakhstan (Kremenetski et al., 1997). In most cases the depth of peat does not exceed 1–2 m. In rare cases the depth can reach up to 3–4 m (Novikov, 1976; Orlova, 1990; Kremenetski et al., 1997). Depth of peat in swamps can reach up to 2.5 m (Orlova, 1990; Kremenetski et al., 1997).

4. Synthesis of existing data on peatland depths

Providing a database for accurate estimates of peatland depths in the WSL is problematic for several reasons. Some depth measurements have been obtained for the WSL during detailed geological prospecting in the forest belt and in one instance there are reported to be about 4000 peat depth measurements for peatlands in this zone (Ivanov and Novikov, 1976). However, in most cases the exact georeferenced position of these measurement points is not available. Many of the available measurements of peatland thickness were obtained from exposed sections, particularly along river valleys. These data may overestimate regional peat depths as peat deposits in river valleys tend to be relatively thick compared to adjacent uplands. Many of the available peat depth measurements come from geobotanical studies of peatland vegetation history. With such paleobotanic studies there is a bias towards sampling the deepest part of the peatland. In general, peat depths from sites with less than 50–70 cm are not reported by most studies, even when such shallow deposits are encountered. Very few measurements of peat depth have been taken from peatlands containing permafrost, and those that are available are not properly georeferenced (Novikov and Usova, 1983).

The available georeferenced data (Table 1) on peat depths show that the majority of sites possess less than 5 m of peat accumulation (Figs. 7 and 8). Accumulations deeper than this are found south of 60°N, with the

Table 1
Peat depth measurements available from specific sites in the West Siberian Lowland

Site Number	Latitude N	Longitude E	Peat depth, cm	Reference
1	61° 35′	73° 20′	250	Liss and Berezina (1981)
2	60° 50′	76° 50′	400	Liss and Berezina (1981)
3	61° 10′	76° 35′	270	Liss and Kulikova (1967)
4	59° 07′	77° 30′	170	Liss and Berezina (1981)
5	60° 10′	72° 50′	600	Liss and Berezina (1981)
6	60° 10′	72° 50′	480	Liss and Berezina (1981)
7	58° 00′	73° 30′	425	Liss and Berezina (1981)
8	59° 22′	68° 57′	300	Neustadt (1967)
9	58° 46′	68° 45′	550	Volkov, Gurtovaya et al. (1973)
10	60° 20′	78° 24′	345	Glebov et al. (1974); Glebov (1988)
11	58° 40′	81° 30′	575	Liss and Berezina (1981)
12	56° 15′	84° 00′	500	Liss and Berezina (1981)
13	56° 15′	84° 00′	150	Liss and Berezina (1981)
14	56° 15′	84° 00′	120	Liss and Berezina (1981)
15	58° 35′	76° 30′	220	Liss and Berezina (1981)
16	56° 30′	83° 30′	375	Liss and Berezina (1981)
17	56° 30′	83° 30′	445	Liss and Berezina (1981)
18	56° 30′	83° 30′	275	Liss and Berezina (1981)
19	56° 30′	83° 30′	200	Liss and Berezina (1981)
20	56° 30′	83° 30′	40	Liss and Berezina (1981)
21	55° 20′	79° 40′	310	Liss and Berezina (1981)
22	55° 20′	79° 40′	135	Liss and Berezina (1981)
23	57°	84°40′	320	Firsov et al. (1985)
24	60°55′	76°35′	400	Firsov et al. (1985) Neustadt, Zelikson (1971)
25	60°37′	75°20′	200	Firsov et al. (1985) Neustadt et al. (1974)
26	56°49′	84°35′	250	Firsov et al. (1985); Arkhipov and Votakh (1980)
27	58°20′	83°30′	175	Firsov et al. (1985)
28	58°20′	83°30′	375	Khotinsky (1977)
29	56°52′	83°05′	400	Khotinsky (1977)
30	56°52′	83°05′	275	Khotinsky (1977)
31	65°41′	64°25′	140	Firsov et al. (1985)
32	61°30′	76°55′	325	Neustadt et al. (1974)
33	63°35′	65°15′	380	Firsov et al. (1985)
34	69°57′	83°35′	174	Firsov et al. (1974, 1985)
35	67°03′	85°59′	220	Levina and Sukhorukova, 1976
36	66°42′	79°44′	340	Peteet et al. (1998)
37	66°48′	65°46′	150	Koshkarova et al. (1999)
38	60°30′	86°40′	425	Karpenko, (1996)
39	60°40′	89°30′	400	Karpenko, (1996)
40	59°23′	76°54′	550	Glebov et al. (1997)
41	67°26′	86°35′	190	Koshkarova et al. (1975); Starikov and Zhidovlenko (1975)
42	67°26′	86°35′	150	Kind, 1974; Levkovskayaa et al. (1970)
43	58°49′	92°07′	158	Koshkarova, (1975, 1981)
44	69°30′	86°	80	Starikov and Zhidovlenko, 1975
45	62°52′	88°08′	125	Koshkarova, (1981)
46	62°40′	89°10	279	Koshkarova, (1981); Starikov and Zhidovlenko (1981)
47	57°43′	93°16′	243	Koshkarova (1981); Starikov and Zhidovlenko (1981)
48	60°23′	90°00′	180	Starikov and Zhidovlenko (1981)
49	54°50′	83°01′	568	Firsov et al. (1982)
50	60°20′	78°07′	170	Arkhipov et al. (1980)
51	63°40′	65°50′	105	Arkhipov et al. (1980)
52	56°20′	84°34′	780	Piavchenko et al. (1973); Piavchenko (1985)
53	54°56′	81°00′	305	Levina et al. (1987); Orlova (1990)
54	60°31′	77°40′	195	Glebov (1988)
55	68°20′	71°20′	430	Vasilchuk et al. (1983)
56	69°23′	72°33	510	Vasilchuk et al. (1983)
57	73°40′	70°05′	250	Vasilchuk et al. (1983)
58	67°05′	68°30′	400	Vasilchuk et al. (1983)
59	68°40′	71°40′	460	Vasilchuk et al. (1983)
60	68°25′	71°00′	150	Vasilchuk et al. (1983)
61	68°21′	71°53′	150	Vasilchuk et al. (1983)
62	68°21′	71°53′	350	Vasilchuk et al. (1983)

Table 1 (*continued*)

Site Number	Latitude N	Longitude E	Peat depth, cm	Reference
63	63°40′	71°00′	350	Khotinsky and Klimanov (1985) Chichagova and Cherkinsky (1988)
64	61°40′	71°20′	380	Karavaeva, (1982); Chichagova and Cherkinsky (1988)
65	61°40′	71°20′	100	Karavaeva, (1982); Chichagova and Cherkinsky (1988)
66	61°40′	71°20′	175	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
67	61°40′	71°20′	25	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
68	61°40′	71°20′	155	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
69	61°40′	71°20′	200	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
70	61°40′	71°20′	75	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
71	60°40′	80°30′	350	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
72	60°40′	80°30′	230	Chichagova and Cherkinsky (1988)
73	60°40′	80°30′	120	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
74	60°40′	80°30′	100	Chichagova and Cherkinsky (1988)
75	60°40′	80°30′	37	Chichagova and Cherkinsky (1988)
76	60°40′	80°30′	180	Chichagova and Cherkinsky (1988)
77	59°	69°	475	Chichagova and Cherkinsky (1988)
78	58°20′	84°	600	Glebov (1988)
79	59°02′	77°24′	355	Firsov et al. (1985); Neustadt et al. (1974)
80	60°37′	69°12′	170	Krivonogov (1988)
81	58°05′	69°59′	380	Krivonogov et al. (1985)
82	59°36′	68°17′	350	Krivonogov, (1988)
83	59°43′	69°32′	450	Krivonogov (1988)
84	60°01′	78°55′	320	Krivonogov (1988)
85	55°08′	80°51′	822	Orlova, L.A. (this paper)
86	57°42′	85°16′	250	Krivonogov, (1988)
87	59°37’	89°33′	260	Orlova, L.A. (this paper)
88	59°37′	89°33′	300	Orlova, L.A. (this paper)
89	63°02′	88°53′	500	Orlova, L.A. (this paper)
90	58°16′	91°09′	140	Orlova, L.A. (this paper)
92	55°02′	82°27′	380	Orlova, 1990
94	54°48′	81°07′	238	Orlova, 1990; Klimanov et al. (1987)
95	54°18′	84°15′	420	Orlova, L.A. (this paper)
96	58°15′	85°20′	640	Blyakharchuk and Sulerzhitsky (1999)
97	67°40′	73°00′	30	Novikov et al. (1999)
98	65°45′	74°35′	280	Novikov et al. (1999)
99	65°45′	74°35′	325	Novikov et al. (1999)
100	65°45′	74°35′	70	Novikov et al. (1999)
101	64°45′	70°40′	140	Malyasova et al. (1991)
102	64°45′	70°40′	60	Novikov et al. (1999)
103	64°45′	70°40′	40	Novikov et al. (1999)
104	64°45′	70°40′	50	Novikov et al. (1999)
105	64°45′	70°40′	65	Novikov et al. (1999)
106	64°45′	70°40′	120	Novikov et al. (1999)
107	64°45′	70°40′	50	Novikov et al. (1999)
108	64°45′	70°40′	60	Novikov et al. (1999)
109	65°10′	77°00′	35	Novikov et al. (1999)
110	65°10′	77°00′	30	Novikov et al. (1999)
111	65°10′	77°00′	40	Novikov et al. (1999)
112	65°10′	77°00′	160	Novikov et al. (1999)
113	65°10′	77°00′	40	Novikov et al. (1999)
114	65°10′	77°00′	60	Novikov et al. (1999)
115	65°10′	77°00′	25	Novikov et al. (1999)
116	65°10′	77°00′	90	Novikov et al. (1999)
117	65°10′	77°00′	65	Novikov et al. (1999)
118	65°10′	77°00′	380	Novikov et al. (1999)
119	65°10′	77°00′	180	Novikov et al. (1999)
120	64°40′	76°40′	160	Novikov et al. (1999)
121	64°40′	76°40′	85	Novikov et al. (1999)
122	64°40′	76°40′	140	Novikov et al. (1999)
123	64°40′	76°40′	100	Novikov et al. (1999)
124	64°40′	76°40′	215	Novikov et al. (1999)
125	64°40′	76°40′	135	Novikov et al. (1999)
126	64°40′	76°40′	160	Novikov et al. (1999)

Table 1 (*continued*)

Site Number	Latitude N	Longitude E	Peat depth, cm	Reference
127	64°40′	76°40′	60	Novikov et al. (1999)
128	63°10′	71°30′	150	Novikov et al. (1999)
129	63°10′	71°30′	280	Novikov et al. (1999)
130	61°30′	74°00′	100	Novikov et al. (1999)
131	61°30′	74°00′	230	Novikov et al. (1999)
132	61°30′	74°00′	300	Novikov et al. (1999)
133	61°00′	77°00′	350	Novikov et al. (1999)
134	61°00′	77°00′	390	Novikov et al. (1999)
135	57°15′	66°40′	160	Novikov et al. (1999)
136	57°15′	66°40′	300	Novikov et al. (1999)
137	60°10′	72°50′	500	Pitkänen et al. (2002)
138	60°10′	72°50′	454	Pitkänen et al. (2002)
139	60°10′	72°50′	340	Pitkänen et al. (2002)

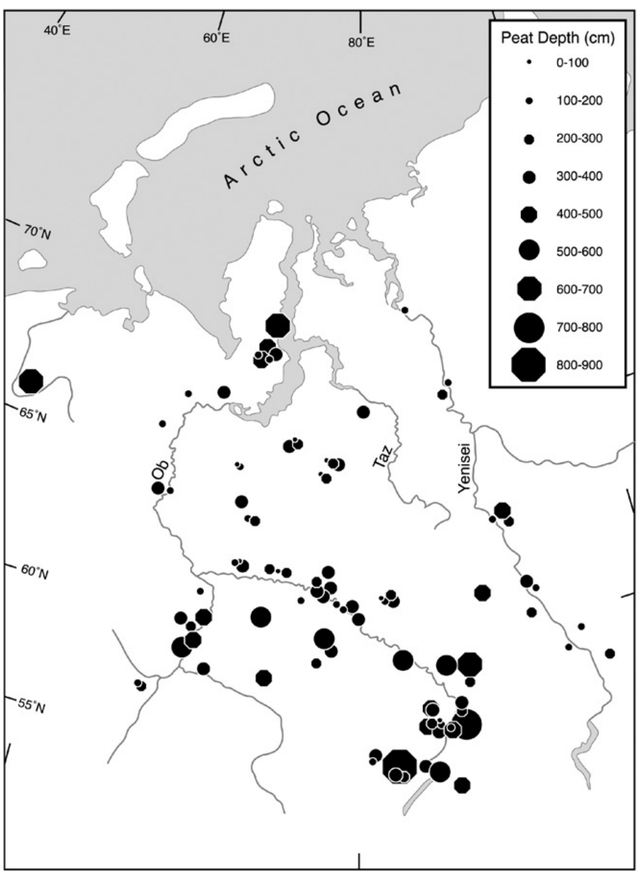

Fig. 7. Locations and general depths of available peatland depth measurements.

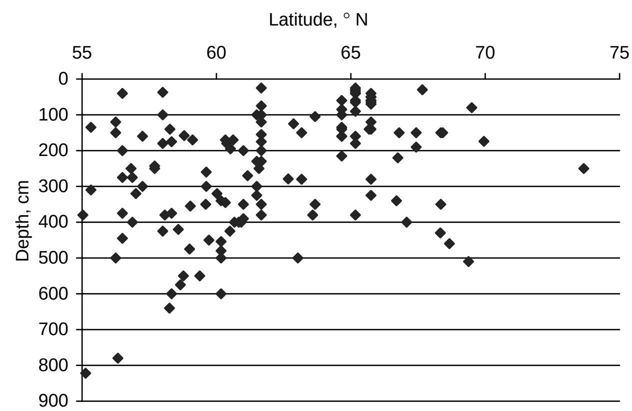

Fig. 8. Relationship between latitude and peatland depth.

deepest reported peatland (>800 cm) occurring at a site located near 55° N. The mean, median and modal peat depths in the WSL as calculated from the available data are 256, 207 cm and 150 cm, respectively. The standard deviation of the peat depths is 166 cm. There is no statistically significant latitudinal trend in peatland depths across the WSL (Fig. 8). Nor are there significant differences in average depths between different peatland zones except in the case of the Flat Eutrophic and Mesotrophic (*Carex*-*Hypnum* and forest) Bog Zone and the Eutrophic (*Phragmites*) and Brackish Bog Zone in the south, which have deeper deposits than more northerly zones.

5. Estimates of peat volume and potential carbon storage in West Siberia today

Neustadt (1971) published the first estimation of the total volume of peat stored in West Siberia (Table 2). His estimate was limited to the forest and forest-steppe belt. According to Neustadt, the forest and forest-steppe peatlands of West Siberia contain 60% of the peat stock of the USSR and 30% of the world peat stock. Total peat area in the forest and forest-steppe belts of the West Siberia was estimated 325,380 km^2 (98% within the forest belt). The volume of peat was estimated to be 93,077 million metric tons (98.8% within the forest belt). That estimation was based upon data of the Geoltorforazvedka (1970) as summarized on the map of West Siberian peatlands. The estimate is of somewhat limited

Table 2
Estimates of peatland area, peat mass (volume) and carbon mass for the West Siberian Lowland.

Peatland area (km^2)	Peat mass	Carbon mass, tons	References
325,380 (depth >0.5 m)	93,077,000,000 tons	53,984,660,000	Neustadt, (1971)
341,000 (depth >0.5 m)	109,700,000,000 tons	63,626,000,000	Tiuremnov, (1976)
1,000,000 (in non-permafrost area)	95,000,000,000 m^3		Liss and Beresina, (1981)
319,000 (depth >0.5 m) 457,000 (depth 0-0.5 m)			Sabo et al. (1981)
400,000	90,000,000,000 tons	52,200,000,000	Davydova and Rachkovskaya, (1990)
464,000(depth >0.5 m) 624,000 (depth 0-0.5 m)	99,740,000,000 tons	51,713,000,000	Efremov and Efremova, (2001)
583,000(depth >0.3 m) 408,000 (depth 0-0.3 m)	84,262,800,000 tons	44,658,600,000	Vompersky et al. (1999)

value because it does not include the peatlands in the tundra regions of the WSL. In addition, data on peat depth in areas with permafrost were scarce owing to the difficulty of coring frozen peat. Another source of uncertainty in the estimate was resolution of the total area and average depth of forested peatlands. This type of peatland is quite common in southern and central portions of the WSL and was likely under-represented in the Geoltorforazvedka (1970) mapping. According to the criteria applied by Geoltorforazvedka, only peatlands deeper than 50 cm were included in their maps. This does not pose a serious problem for southern regions of West Siberia where bogs are normally deeper than 1 m, but this in an important source of underestimation of the peatland area in northern regions.

All later estimations of the area and volume of peatland areas in the WSL (including the most recent published in World Peat Resources, 1996) were largely based upon the data published by Neustadt with minor corrections, and upon a revised peatlands map published by the State Hydrological Institute (1976). These primary data form the foundation for estimations of the peat and carbon store of the entire former USSR and Russian Federation. Tiuremnov (1976), Kivinen and Pakarinen (1981), Markov and Olenin (1984), Botch et al. (1994, 1995), Efremov et al. (1994) and Vompersky et al. (1994, 1999) have all published such estimates and include the peatlands of the WSL in calculating total peatland cover and volume for the former USSR or Russian Federation.

Estimates of the total carbon contained in the peatlands of the WSL vary considerably depending upon the methods used and exact geographic areas included. All calculations, except those of Efremov et al. (1994), were mainly concerned with estimating the peatland carbon storage for all of Russia without any special reference to the amount in West Siberia alone. Efremov et al. (1994) estimated the total carbon storage of the peatlands to be 53,836 million metric tons. It is widely recognized that given the problems with the primary data discussed above, this estimate is extremely tentative (Botch et al., 1995).

6. West Siberian peatland history

The history of peatland development and environmental change in the WSL has long been an object of research by Russian paleoecologists. The first paleoecological data on the history of peat bogs from the WSL appeared in the early 20th century. Neustadt (1967) provides a detailed overview of previously published fossil pollen and peat stratigraphic records for West Siberia. Early investigations were concentrated in river valleys and most data come from natural outcrops exposed along riverbanks. The stratigraphic evidence demonstrated two main pathways for peat bog initiation: (1) peatlands formed on mineral ground (silt or sand), suggesting paludification; and (2) peat growth initiated on gyttja suggesting a lacustrine environment prior to a peatland emergence and terrestrialization. Botanical analysis of plant fossils from the peats suggested that eutrophic bogs were present in the early Holocene and preceded development of oligotrophic bogs.

With the development of radiocarbon dating it became possible to determine how old West Siberian peat deposits were. The first radiocarbon dates for the peatlands were obtained in the late 1960s (Liss and Kulikova, 1967; Neustadt, 1967). Subsequently, radiocarbon-dated peat pollen sequences obtained from peat sections appeared in the literature (Levkovskaya et al., 1970; Volkov et al., 1973; Glebov et al., 1974). Several of other pollen diagrams were produced with chronologies provided by correlating pollen stratigraphies with radiocarbon-dated sequences from other peatlands.

Soon after the first radiocarbon dates were obtained, hypotheses regarding the initiation and spatial development of the peatlands, and the rate of the peat accumulation in the WSL were formulated. Basal radiocarbon dates from the peats suggested that peatlands did not form until the end of the Pleistocene. One hypothesis was that during the last glaciation, northwestern Siberia was covered with ice. This ice kept rivers from discharging to the Arctic Ocean, leading to the formation of a huge lake south of the ice. When the glacial ice had melted, normal discharge of rivers to the ocean was re-established, the lake drained and peat bogs formed on the former lake bed. Piavchenko (1955) and more recently Grosswald (1998) supported this model of peatland initiation, but it remains virtually without solid evidence in its favour. Velichko et al. (1984, 2000) and Faustova and Velichko (1992) argued that there is no evidence of continuous ice cover in West Siberia during the LGM. Thus, there was no blockage of river flow, and no proglacial lake. They suggest that exceptionally dry and cold climatic conditions and extensive permafrost dominated the region (Velichko and Nechaev, 1984). In this case, the aridity of the full glacial environment promoted aeolian activity and precluded peatland development.

Neustadt (1976) proposed the first detailed model of Holocene peatland initiation and expansion in the WSL (Fig. 9a). The model was based upon a very limited number of basal peat radiocarbon dates. To supplement the limited evidence he used pollen zone correlation to provide chronologies for sections that lacked radiocarbon dates. Neustadt based his model for the WSL on a model developed for the growth of Chistik Bog in the Novgorod region (southeast of Saint Petersburg). Palaeoecological work suggested that the first peat accumulation at Chistik Bog started in a few discrete nuclei within the present-day area of the peatland. Then these smaller bogs gradually expanded and all the nuclei merged into one large peatland complex. This concept of the so-called "aggressive" bog expansion was applied at much larger scale for the West Siberian lowland. Neustadt concluded that at around 9000 cal yr BP the total area of peatlands in West Siberia was very limited and confined to scattered bogs. As the Holocene progressed the bogs gradually increased in areal extent until the present peatland complexes developed. At the beginning peat accumulation started in eutrophic bogs. With the evolution of bogs they were gradually transformed into mesotrophic and later into oligotrophic bogs. According to Neustadt's estimates, if the same rate of increase in the bog area is sustained, during the next 1000 years peatlands will cover all of the middle and southern taiga belt. More recently Liss and Berezina (1981) and Malik (1992) have reached similar conclusions regarding peatland development in the WSL and lend support for this conclusion.

Glebov (1988) has proposed an alternative to the conclusions reached by Neustadt (Fig. 9b). Using largely the same data as Neustadt, Glebov postulated that the starting date for peatland development was about 10,000 Cal yr BP and the process of spatial expansion of the bogs has become slower through time. He suggested that the modern peatlands occupy essentially all areas that are potentially suitable for the peat accumulation and there will be no significant future expansion (Glebov et al., 1997). His conclusions are

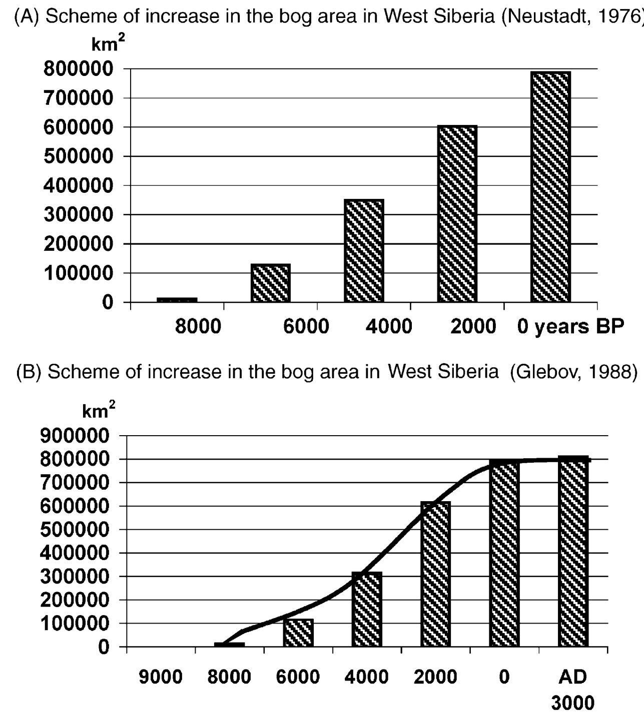

Fig. 9. Increase in the bog area in West Siberia during the Holocene. A after Neustadt, 1976; B after Glebov, 1988.

shared by some other Russian scientists (Karpenko, 1996).

On a smaller scale, Karavaeva (1982) obtained evidence about peat initiation ages from two key study areas in the Oligotrophic Bog Zone near the Ob' River. The main target of her study was to establish changes in the soils that develop as a consequence of the peatland initiation. These data demonstrated that the upland peatlands are of early Holocene age, while bogs formed on former lakes on the river Ob' terraces are often younger.

The theories of Holocene peatland expansion outlined above were constructed for unfrozen oligotrophic bogs in the southern half of the West Siberian lowland. Palaeoecological data for the northern Polygonal Bog and Flat Mound Bog and Large Mound Bog zones are more limited. Much of the work in the north has centred on the origin of the large frozen hill-bogs. Most scientists (Dranitsyn, 1914; Gorodkov, 1928; Andreev, 1935) thought that the large hill-bogs were formed by the permafrost activity. Some scientists, based upon the evidence of destruction of the upper part of some frozen hills, suggested that they were remnant features formed by thermal erosion (Piavchenko, 1955, 1971). The most valuable set of data pertaining to northern peatland development was obtained by the State Hydrological Institute in Saint Petersburg (Ivanov and Novikov, 1976; Novikov and Usova, 1983; Malyasova et al., 1991; Novikov et al., 1999). The study produced a total of

41 radiocarbon dates from large frozen hill-bogs and unfrozen depressions in the northern part of the WSL. Basal dates of peat from the hill-bogs range from 10,300 to 6000 cal yr BP. Basal dates from unfrozen depressions range from 5400 cal yr BP to 3000 yr BP. The age of the uppermost peat layer on hills is between 100 and 500 cal yr BP. The oldest of these radiocarbon dates show that the peat accumulation started in the northern part of the West Siberian Lowland at the same time as in the southern part. It is also clear that basal peat in unfrozen depressions is younger than basal peat in the frozen hills. It was concluded that maximum bog development and peat accumulation occurred between ~9000 and 5300 yr BP. Then climate became colder and peat accumulation slowed. During the last 2500 years the rate of peatland expansion and peat accumulation has been very low. It was also suggested that larger mound-bogs were formed earlier than the flat mound-bogs, which only date to the last 2500 years.

7. Synthesis of existing peatland radiocarbon dates

In order to provide a more comprehensive analysis of peatland development and peat accumulation history for the WSL we have collated and analysed all of the available published basal radiocarbon dates from peat sections in the region. In some cases radiocarbon dates of wood recovered from the bases of peat sections were used in place of dates on peat. We have also collected numerous other dates that were previously unpublished, or published without appropriate information about stratigraphic context and geographic location. These dates were archived at the Radiocarbon Laboratory in Novosibirsk.

A total of 137 basal peat dates is available from the WSL (Figs. 10–12; Table 3). The frequency distribution of the basal radiocarbon dates (Fig. 10) shows that many peatlands were initiated in the early Holocene (11,000–10,000 cal BP). There is a decline in initiation after 9000 cal BP, reaching a nadir at 4000 cal BP and then a slight increase in initiation. The number of peatlands established in the late Holocene may be under-represented because younger peatlands tend to be shallower as they have had less time to develop and are less likely to be chosen for analysis by peatland palaeocecologists, who traditionally seek long stratigraphic sections for their work.

When the available radiocarbon dates for the initiation of peatlands are mapped or graphed by latitude it appears that peat accumulation started simultaneously in the northern and southern parts of WSL at approximately 11,000–10,000 cal BP (Figs. 11 and 12). A few older dates come from river valleys in the south and may reflect isolated bogs that existed towards the end of the Late Glacial. It is also possible that these

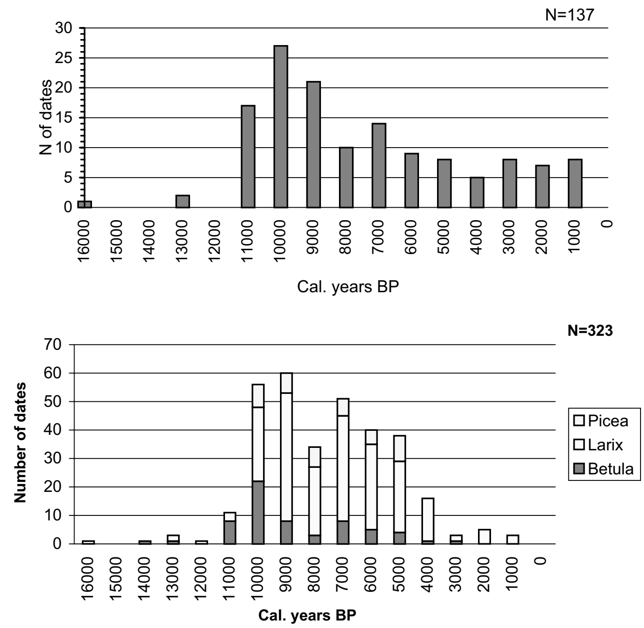

Fig. 10. Histograms of radiocarbon dates of peatland initiation in the West Siberian Lowland and macrofossils of trees from sites beyond the treeline across northern Eurasia (after MacDonald et al., 2000).

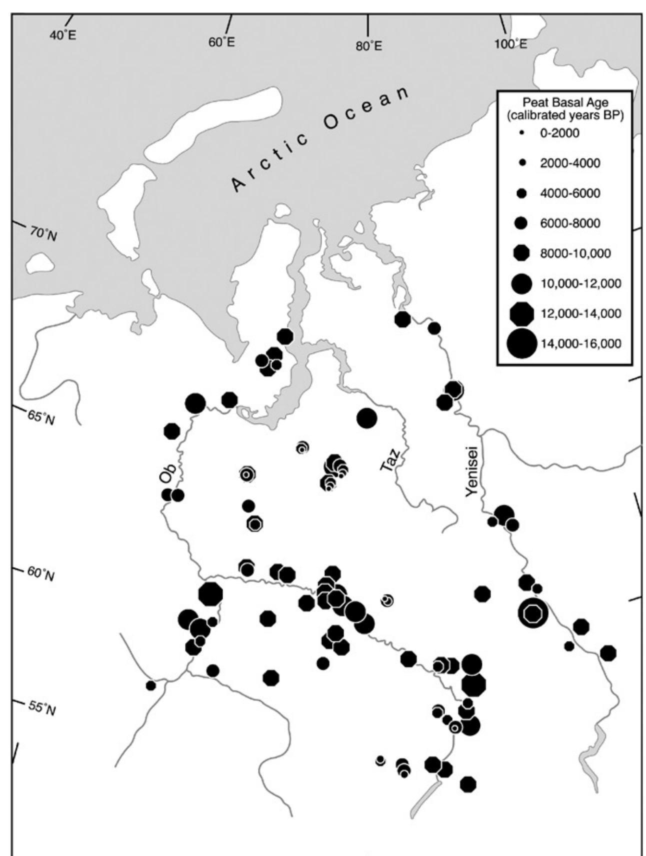

Fig. 11. Locations and general ages of radiocarbon-dated peatland records from the West Siberian Lowlands. Mulitple dates from the same site indicate areas where individual peatland complexes were sampled in detail to reconstruct local development.

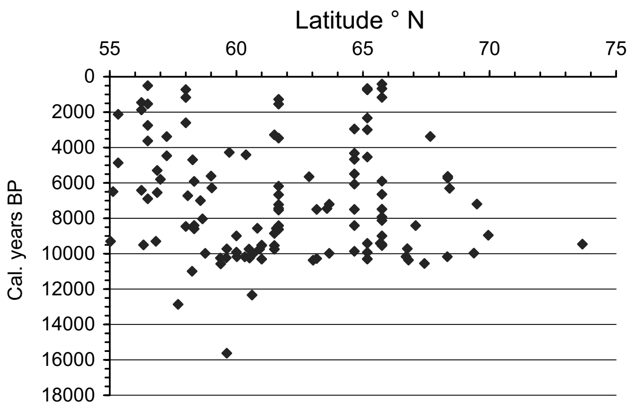

Fig. 12. Relationship between latitude and oldest basal radiocarbon dates from peatland complexes. The graph excludes younger dates collected from detailed sampling of individual sections or peatland complexes.

dates are too old owing the impact of the hard water effect on submergent bryophytes and vascular plants in the peats that initiate through the terrestrialization process (MacDonald et al. 1987). It is also clear that many of the peatland complexes south of approximately 62°N established following 4000 cal BP while none of those north of this latitude initiated after 4000 cal BP.

The mapped distribution of basal ages provides the impression that the peatlands first developed in the large river valleys and then spread onto the interfluve regions (Fig. 11). Although this is possible, it is also likely that this pattern is strongly influenced by the concentration of Russian palaeoecologists on sampling peats exposed along river valleys. It is clear from the map that the number of sampling points away from the river valleys remains very limited.

When peatland depth is compared with basal age there is a very large amount of scatter (Fig. 13). It is impossible to calculate a statistically significant average rate of peat accumulation from these data. Peat sections that are over 10,000 cal BP in age can range in thickness from less than 100 cm to over 500 cm.However, it is also clear that, in general, the maximum depths of younger peatlands are not as great as the maximum depths of older peatlands. For example the maximum depth of peat sections with basal ages of 2000 cal BP or less does not exceed 200 cm.Thus, there appears to be a general upper limit of peat accumulation of roughly 80 cm/1000 years (Fig. 13).

It is worth remembering that in the absence of surface radiocarbon dates, total amounts of peat accumulation over the Holocene is difficult to measure owing to erosion of the upper peat on degrading bogs. Relatively old (up to 4000 cal BP) dates were obtained for peat-organic soils at a depth 30–15 cm from the surface in Bolshsezemelskaya tundra in European Russia (Goryachkin et al., 2000).

8. Peatland initiation and climatic change

The records of peatland initiation are admittedly still relatively sparse over such a huge geographic region, and biased towards river valley sites. However, some preliminary synthesis and analysis can be made regarding peatland history and climatic change in the WSL.

The history of the peatlands suggests that there were few if any bogs in existence during the Late Glacial. At 11,000–10,000 cal yr BP widespread development of peatlands commenced from the northern coastline to at least 55°N latitude in the south. Outside of permafrost sites in the north, peatland initiation slowed during the period 8000–4000 cal yr BP. A resurgence of peatland development strongly expressed south of 62°N commenced in the late Holocene.

The initiation of extensive peatland development between ~11,000 and 8,000 cal BP corresponds well with palaeoclimatic data relating to the postglacial warming of northern Siberia. Extensive collections of tree macrofossils (Fig. 10) indicates that the taiga vegetation of western Siberia developed during this same period (Krementski et al., 1998; MacDonald, et al., 2000). The development of forest indicates the establishment of climatic conditions that were warm enough and moist enough to promote boreal peatland development at this time. The initiation of these climatic conditions across northern Eurasia likely relates to high summer insolation, the final deglaciation of Fennoscandia and warming of the northern Atlantic (Velichko et al., 1997; MacDonald et al, 2000).

Decreases in peatland initiation in the central areasof the peatlands between 8000 and 4000 cal yr BP and the scarcity of peatlands in the far south may all relate to warm and dry mid-Holocene conditions. Warmer than present conditions during the period ~9000–4000 cal yr BP and subsequent cooling during the late Holocene is evidenced by reconstruction of permafrost degradation and subsequent redevelopment, and radiocarbon-dated pollen records and plant macrofossil evidence from the WSL and adjacent regions (Baulin et al., 1967; Velichko and Nechaev, 1984; Khotinsky, 1984; Kremenetski et al., 1998; MacDonald et al., 2000). Radiocarbon-dated tree macrofossils from beyond the modern treeline suggest a summer warming on the order of 4–5°C between 8000 and 4000 yr BP (Kremenetski et al., 1998; MacDonald et al., 2000) during the early to mid-Holocene. It is likely that there was a northward retreat of permafrost and an increase in active layer depth during the middle Holocene. Cooling, increased effective moisture and changes in drainage caused by the southward movement of the permafrost to its modern position after 4000 cal yr BP appear to have generated a minor increase in peat initiation at that time, including the initial development of a number of peatlands in the far south.

Table 3
Published and unpublished radiocarbon dates of peatland intitiation from the West Siberian Lowland

Site Number	Latitude N	Longitude E	Basal date	Calibrated age	Lab number	Reference
1	61° 35′	73° 20′	7870 ± 60	8572	TA-521	Liss and Berezina (1981)
2	60° 50′	76° 50′	7860 ± 70	8566	TA-520	Liss and Berezina (1981)
5	60° 10′	72° 50′	8140 ± 80	8994	TA-933	Liss and Berezina (1981)
6	60° 10′	72° 50′	8900 ± 90	9912	TA-934	Liss and Berezina (1981)
7	58° 00′	73° 30′	7740 ± 70	8460	TA-506	Liss and Berezina (1981)
8	59° 22′	68° 57′	9280 ± 200	10247		Neustadt, (1967)
9	58° 46′	68° 45′	9000 ± 100	9979	SOAN-395	Volkov, Gurtovaya et al. (1973)
10	60° 20′	78° 24′	9200 ± 100	10177	KRIL-88	Glebov et al. (1974); Glebov (1988)
11	58° 40′	81° 30′	7260 ± 60	8030	TA-666	Liss and Berezina (1981)
12	56° 15′	84° 00′	5660 ± 80	6417	TA-911	Liss and Berezina (1981)
13	56° 15′	84° 00′	1930 ± 60	1870	TA-910	Liss and Berezina (1981)
14	56° 15′	84° 00′	1580 ± 60	1457	TA-909	Liss and Berezina (1981)
15	58° 35′	76° 30′	6120 ± 80	7000	TA-618	Liss and Berezina (1981)
16	56° 30′	83° 30′	6070 ± 90	6895	TA-598	Liss and Berezina (1981)
17	56° 30′	83° 30′	3380 ± 80	3626	TA-907	Liss and Berezina (1981)
18	56° 30′	83° 30′	2610 ± 70	2748	TA-906	Liss and Berezina (1981)
19	56° 30′	83° 30′	1640 ± 70	1531	TA-905	Liss and Berezina (1981)
20	56° 30′	83° 30′	440 ± 80	504	TA-904	Liss and Berezina (1981)
21	55° 20′	79° 40′	4350 ± 70	4868	TA-596	Liss and Berezina (1981)
22	55° 20′	79° 40′	2140 ± 80	2122	TA-597	Liss and Berezina (1981)
23	57°	84°40′	5040 ± 115	5796	SOAN-77	Firsov et al. (1985)
24	60°55′	76°35′	8780 ± 35	9740	SOAN-173	Firsov et al. (1985)
						Neustadt and Selikson, (1971)
25	60°37′	75°20′	8600 ± 95	9521	SOAN-186	Firsov et al. (1985)
						Neustadt et al. (1974)
26	56°49′	84°35′	8370 ± 65	9300	SOAN-337-T	Firsov et al. (1985)
						Arkhipov and Votakh, (1980)
27	58°20′	83°30′	7890 ± 90	8594	SOAN-351	Firsov et al. (1985)
28	58°20′	83°30′	5150 ± 120	5914	Mo-467	Khotinsky, (1977)
29	56°52′	83°05′	5760 ± 130	6544	Mo-434	Khotinsky, (1977)
30	56°52′	83°05′	4570 ± 170	5295	Mo-433	Khotinsky, (1977)
31	65°41′	64°25′	8400 ± 100	9410	SOAN-654	Firsov et al. (1985)
32	61°30′	76°55′	8010 ± 40	8853	SOAN-777	Neustadt et al. (1974)
33	63°35′	65°15′	6600 ± 100	7450	SOAN-687	Firsov et al. (1985)
34	69°57′	83°35′	8020 ± 105	8954	SOAN-62	Firsov et al. (1974, 1985)
35	67°03′	85°59′	8720 ± 85	9720	SOAN-611	Levina and Sukhorukova, (1976)
						Firsov et al. (1985)
36	66°42′	79°44′	9200 ± 60	10167	CAMS-2428	Peteet et al. (1998)
37	66°48′	65°46′	9370 ± 40	10359	SOAN-3105	Koshkarova et al. (1999)
38	60°30′	86°40′	8765 ± 120	9745	KRIL-717	Karpenko, (1996)
39	60°40′	89°30′	9025 ± 180	9985	KRIL-719	Karpenko, (1996)
40	59°23′	76°54′	9510 ± 140	10576	KRIL-430	Glebov et al. (1997)
42	67°26′	86°35′	9480 ± 120	10550	GIN-	Kind, (1974)
						Levkovskaya et al. (1970)
44	69°30′	86°	6280 ± 70	7195	KRIL-132	Starikov and Zhidovlenko, (1975)
45	62°52′	88°08′	4925 ± 45	5649	KRIL-290	Koshkarova (1981)
48	60°23′	90°00′	3950 ± 300	4410	KRIL-240	Starikov and Zhidovlenko (1981)
49	54°50′	83°01′	8710 ± 105	9700	SOAN-1860	Firsov et al. (1982)
50	60°20′	78°07′	2480 ± 30	2585	SOAN-1183	Arkhipov et al. (1980)
51	63°40′	65°50′	6300 ± 50	7205	SOAN-968	Arkhipov et al. (1980)
52	56°20′	84°34′	9625 ± 100	10720	TA-1137	Piavchenko et al. (1973)
						Piavchenko, (1985)
53	54°56′	81°00′	5490 ± 40	6291	SOAN-2176	Levina et al. (1987); Orlova, (1990)
54	60°31′	77°40′	9255 ± 20	10246	KRIL-325	Glebov, (1988)
55	68°20′	71°20′	9230 ± 50	10172	GIN-2479	Vasilchuk et al. (1983)
56	69°23′	72°33	8960 ± 140	9967	MGU-816	Vasilchuk et al. (1983)
57	73°40′	70°05′	8500 ± 120	9460	LU-1151	Vasilchuk et al. (1983)
58	67°05′	68°30′	7690 ± 110	8414	LU-1081	Vasilchuk et al. (1983)
60	68°25′	71°00′	5550 ± 150	6309	BasgGI-63	Vasilchuk et al. (1983)
61	68°21′	71°53′	4990 ± 250	5726	BasgGI-62	Vasilchuk et al. (1983)
62	68°21′	71°53′	4900 ± 250	5630	BasgGI-67	Vasilchuk et al. (1983)

Table 3 (*continued*)

Site Number	Latitude N	Longitude E	Basal date	Calibrated age	Lab number	Reference
63	63°40′	71°00′	9000±50	9979	IGAN-387	Khotinsky and Klimanov, (1985) Chichagova and Cherkinsky (1988)
64	61°40′	71°20′	7700±100	8416	IGAN-142	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
65	61°40′	71°20′	1670±50	1545	IGAN-134	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
66	61°40′	71°20′	5850±50	6670	IGAN-135	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
67	61°40′	71°20′	1340±30	1279	IGAN-136	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
68	61°40′	71°20′	6700±100	7532	IGAN-137	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
69	61°40′	71°20′	7900±60	8626	IGAN-138	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
70	61°40′	71°20′	6600±50	7436	IGAN-139	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
71	60°40′	80°30′	5380±60	6186	IGAN-32	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
72	60°40′	80°30′	6360±70	7228	IGAN-33	Chichagova and Cherkinsky (1988)
73	60°40′	80°30′	3270±60	3469	IGAN-34	Karavaeva, (1982) Chichagova and Cherkinsky (1988)
74	60°40′	80°30′	1250±30	1171	IGAN-6	Chichagova and Cherkinsky (1988)
75	60°40′	80°30′	820±30	721	IGAN-7	Chichagova and Cherkinsky (1988)
76	60°40′	80°30′	2500±30	2600	IGAN-8	Chichagova and Cherkinsky (1988)
77	59°	69°	4890±40	5612	IGAN-211	Chichagova and Cherkinsky (1988)
78	58°20′	84°	7640±230	8402	KRIL-558	Glebov, (1988)
79	59°02′	77°24′	5450±35	6280	SOAN-200	Firsov et al. (1985) Neustadt et al. (1974)
80	60°37′	69°12′	10430±170	12336	SOAN-1107	Krivonogov, (1988)
81	58°05′	69°59′	5880±70	6724	SOAN-2082	Krivonogov et al. (1985)
82	59°36′	68°17′	9300±65	10235	SOAN-2255	Krivonogov, (1988)
83	59°43′	69°32′	3870±40	4277	SOAN-2595	Krivonogov, (1988)
84	60°01′	78°55′	9230±45	10171	SOAN-2685	Krivonogov, (1988)
85	55°08′	80°51′	5720±100	6489	SOAN-2808	Orlova, L.A., (this paper)
86	57°42′	85°16′	10945±45	12865	SOAN-2659	Krivonogov, (1988)
87	59°37′	89°33′	8775±80	9727	SOAN-3184	Orlova, L.A., (this paper)
88	59°37′	89°33′	13120±100	15623	SOAN-3179	Orlova, L.A., (this paper)
89	63°02′	88°53′	9395±245	10369	SOAN-3320	Orlova, L.A., (this paper)
90	58°16′	91°09′	4140±35	4691	SOAN-3511	Orlova, L.A., (this paper)
92	55°02′	82°27′	8320±90	9300	SOAN-2232	Orlova, (1990)
94	54°48′	81°07′	2370±70	2350	SOAN-1961B	Orlova, (1990) Klimanov et al., (1987)
95	54°18′	84°15′	8050±40	8979	SOAN-2337	Orlova, L.A., (this paper)
96	58°15′	85°20′	9840±90	10995	GIN-5513	Blyakharchuk and Sulerzhitsky (1999)
97	67°40′	73°00′	3170±170	3373	UPI-302	Novikov et al. (1999)
98	65°45′	74°35′	5110±100	5899	LU-563	Novikov et al. (1999)
99	65°45′	74°35′	5810±70	6647	TA-752	Novikov et al. (1999)
100	65°45′	74°35′	750±60	668	TA-745	Novikov et al. (1999)
101	64°45′	70°40′	8500±50	9466	LU-942	Malyasova et al., 1991
102	64°45′	70°40′	7335±110	8120	UPI-300	Novikov et al. (1999)
103	64°45′	70°40′	7150±80	7925	LU-943	Novikov et al. (1999)
104	64°45′	70°40′	8140±120	8994	UPI-304	Novikov et al. (1999)
105	64°45′	70°40′	1230±140	1164	UPI-296	Novikov et al. (1999)
106	64°45′	70°40′	8660±100	9538	UPI-297	Novikov et al. (1999)
107	64°45′	70°40′	370±90	409	UPI-295	Novikov et al. (1999)
108	64°45′	70°40′	6640±130	7482	UPI-299	Novikov et al. (1999)
109	65°10′	77°00′	860±260	736	LU-928	Novikov et al. (1999)
110	65°10′	77°00′	720±250	662	LU-926	Novikov et al. (1999)
111	65°10′	77°00′	830±160	725	LU-950	Novikov et al. (1999)
112	65°10′	77°00′	9320±120	10300	LU-934	Novikov et al. (1999)
113	65°10′	77°00′	830±160	725	LU-932	Novikov et al. (1999)
114	65°10′	77°00′	2290±150	2330	LU-929	Novikov et al. (1999)
115	65°10′	77°00′	4070±110	4531	LU-930	Novikov et al. (1999)
116	65°10′	77°00’	8930±120	9928	LU-936	Novikov et al. (1999)

Table 3 (*continued*)

Site Number	Latitude N	Longitude E	Basal date	Calibrated age	Lab number	Reference
117	65°10′	77°00′	2900±120	2994	LU-935	Novikov et al. (1999)
118	65°10′	77°00′	8420±180	9415	LU-933	Novikov et al. (1999)
119	65°10′	77°00’	9320±320	10300	LU-931	Novikov et al. (1999)
120	64°40′	76°40′	6630±50	7494	LU-732	Novikov et al. (1999)
121	64°40′	76°40′	4750±110	5490	LU-723	Novikov et al. (1999)
122	64°40′	76°40′	7670±90	8409	LU-717	Novikov et al. (1999)
123	64°40’	76°40′	3900±70	4323	LU-722	Novikov et al. (1999)
124	64°40’	76°40′	5280±240	6070	LU-725	Novikov et al. (1999)
125	64°40′	76°40′	4140±80	4670	LU-719	Novikov et al. (1999)
126	64°40′	76°40′	8810±100	9862	LU-737	Novikov et al. (1999)
127	64°40′	76°40′	2860±90	2953	LU-736	Novikov et al. (1999)
128	63°10′	71°30′	6680±80	7499	LU-562	Novikov et al. (1999)
129	63°10′	71°30′	9220±100	10275	LU-583	Novikov et al. (1999)
130	61°30′	74°00′	3100±140	3281	LU-564	Novikov et al. (1999)
131	61°30′	74°00′	8660±80	9538	LU-559	Novikov et al. (1999)
132	61°30′	74°00′	8800±80	9749	LU-560	Novikov et al. (1999)
133	61°00′	77°00′	8650±50	9535	LU-584	Novikov et al. (1999)
134	61°00′	77°00′	9340±80	10309	LU-581	Novikov et al. (1999)
135	57°15′	66°40′	4010±80	4465	LU-582	Novikov et al. (1999)
136	57°15′	66°40′	3180±110	3378	LU-738	Novikov et al. (1999)
137	60°10′	72°50′	9420±110	10430	Hel-	Pitkänen et al. (2002)
138	60°10′	72°50′	9640±120	10945	Hel-	Pitkänen et al. (2002)
139	60°10′	72°50′	9530±100	10835	Hel-	Pitkänen et al. (2002)

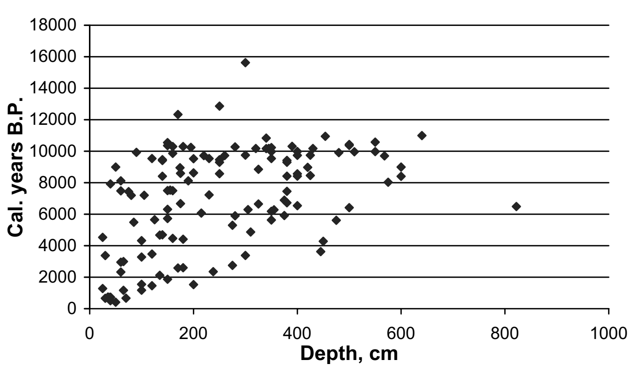

Fig. 13. Relationship between peat section thickness and age.

Conversely, the establishment of colder climates and tundra conditions as the treeline retreated in the far north (Fig. 10) may have decreased peat growth rates and peat initiation there.

9. Conclusions

Numerous studies by Russian scientists provide important data on the distribution of peatlands of West Siberia, peatland structure and depth, and peatland history. However, given the huge expanse of the region, these data points remain relatively sparse. Despite their scarcity, the existing radiocarbon dates for peatland initiation and history suggest there are linkages between Holocene climatic changes and peatland dynamics both in the north and south. The apparent sensitivity of the peatlands to Holocene climate variations suggest it is likely that the peatlands will also respond in a significant manner to the climatic changes of the magnitude anticipated in future "global warming". Owing to the potential impact of the WSL on global climate due to changes in carbon balance and hydrology, it is of crucial importance that we increase our network of modern data and palaeoecological records from the region to ascertain the actual amount of carbon there to anticipate better the magnitude and impact of such responses.

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